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Design and fabrication of an adhesion force tester for the injection moulding process

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ABSTRACT

During the injection moulding process, serious adhesion effects can occur at the interface between the specimen and tool surface during ejection, causing distortions or cracks in the samples, especially for resins such as PMMA, PC and TPU. However, ejection force measurement is not able to measure adhesion force accurately for elastomeric resins during the injection moulding process. A tensile mode adhesion force tester was fabricated to measure the adhesion force between the sample and tool surface during the thermoplastic injection moulding process, especially for elastomeric resins, which have adhesion problems that are both serious and difficult to measure. In addition, three different types of TPU are examined, with their temperature and viscosity being the main factors that affect the adhesion force. Engineers can use the measurements obtained in this work to better understand adhesion and work to reduce it.

1. Introduction

Injection moulding is one of the most widely used approaches for the mass production of plastic parts with complicated geometry. However, there are a number of issues that can reduce the quality of the surfaces of such products. One problem is mould adhesion between the cavity surface and moulded part. Serious adhesion makes it difficult to release the sample from the mould cavity, and results in deformation or cracking on the surface of finished part after demoulding. There are four common approaches to reducing adhesion force. The first is to add a mould release agent into the resin, but this may cause unstable product quality or poor mechanical properties. The second is to apply a mould release agent to the cavity surface, although this approach may be effective for only one or two shots and, therefore, the mould release agent must be applied very often. Furthermore, undesired flow marks may appear on the product surface if the mould release agent is not uniformly applied. The third approach is to improve the ejection system used in the tool. However, tool design may become more complicated when the sample geometry is complex. The final approach is the special handling of the mould surface, such as surface treatments on the tool to change the cavity surface quality, and this approach is effective to overcome mould adhesion in practice.

Treatment of the tool surface has been shown to be a good way to overcome mould adhesion [1,7]. However, there is currently no scientifically-validated approach that can quantitatively measure adhesion force accurately in the injection moulding process, although the contact angle can be measured to assess whether the treatment of the tool surface is effective to alleviate adhesion force. However, it is difficult to persuade engineers to use unauthenticated treatments to address the issue of mould adhesion. Therefore, it is necessary to develop and validate an instrument that can accurately measure adhesion at the interface between the mould surface and moulded part.

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Adhesion is common for both thermosetting and thermoplastic materials, and significant levels of mould adhesion can make the design of tools and selection of process parameters more difficult. Chang and Hwang [1,2] successfully developed a practical apparatus to measure the strength of adhesion force for thermosetting materials, and also studied the effects of process parameters on adhesion force during the IC encapsulation process. Yoshii and Suzuki [3] investigated the release behavior of semiconductor packages, and showed that the release force increased along with the ejection speed, although the change was not significant. However, all the studies mentioned above focused on thermosetting materials in the transfer moulding process, and few works have discussed adhesion in the injection moulding process. Although Sasaki et al. [4] developed an instrument to measure ejection force, they only considered the release behavior of stiff plastics, such as PP, PMMA and PET, which is different from that of rubber-like materials, such as TPU, TPE or TPR. Yamamoto et al. [5,6] found that the use of an extremely thin chemical adsorbed fluorocarbon film on the surface of a tool could significantly reduce the demoulding force for injection moulded PMMA material. The measurements for acquiring the ejection force developed by Sasaki et al. and Yamamoto et al. are used with ejection mode adhesion force testers, with both fitting a force sensor under the ejector pin seating. However, the ejection force acquired in this way may be affected by the friction between the moulded part and core surface. In addition, if the test material is an elastomeric resin with Moony-Rivlin material properties, Chen and Hwang [7] detected that the curve in the adhesion force versus time diagram for TPU with an ejection mode adhesion force tester exhibited a release duration phenomenon, because TPU can sustain significant deformation during the ejection stage. In addition, the rupture interface between moulded part and tool surface did not separate instantly, and the measurement obtained in this way is very much ejection speed dependent, as shown in Fig. 1. As ejection speed increases, the peak force of measuring curve becomes larger. Although the peak force of the measurement is related to the integrated impulse value of the measurement, it can only provide a qualitative description of the adhesion phenomenon, and the actual true adhesion force between the cavity and sample surfaces cannot be characterized by an ejection mode adhesion force tester. Ryntz et al. [8] found that the adhesion force increases along with the size of the gate and melting temperature, and also rises when there is a lower injection speed. Haragas et al. [9] found that using gas to help eject a moulded part could effectively reduce the strength of the adhesion force when ejecting thin products, and also presented a mathematical formula to obtain the demoulding force. Pouzada et al. [10] found the coefficient of friction at the ejection stage depends on the surface texture of the core and the temperature at ejection. They also found that the coefficient of friction was sensitive to temperature, surface roughness and pressure between the contacting surfaces. Nevertheless, their test routine was not designed for the traditional injection moulding process.

This paper presents a newly developed and fabricated tensile mode test instrument for the continuous, accurate measurement of adhesion force. The design concept of the instrument is discussed in detail, and some TPU resins are used to assess the stability and practicability of the instrument. The results show that the instrument can successfully quantify adhesion force, and thus be used to determine the severity of the mould adhesion effect. Engineers can use this instrument to further investigate mould adhesion.

2. Experimental methods

2.1. Concept of acquiring the adhesion force

A TPU test sample partially resists and absorbs ejection force when released from the tool surface, since TPU is a rubber-like material with Moony-Rivlin like properties, and thus different from stiff plastics like ABS, HDPE, PMMA and PC at room temperature. It is, therefore, inappropriate to define adhesion force as the ejection force for rubber-like materials, since the value of this depends significantly on the ejection speed. The basic design concept of the new adhesion force test measurement developed in this work is the *in situ* acquisition of the interfacial tensile adhesive strength between the tool surface and moulded part when opening the mould, and the duration of the test was kept as short as possible.

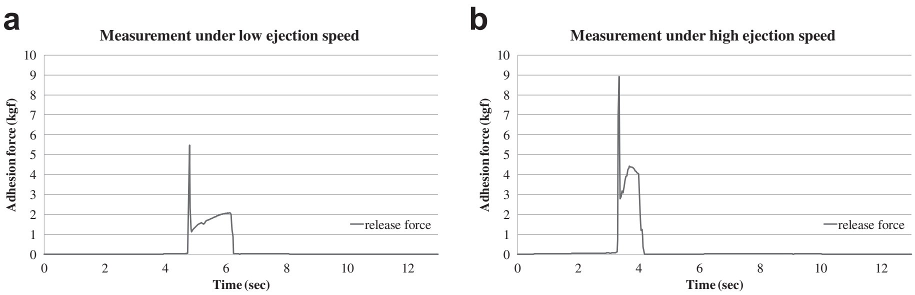

Fig. 1. Typical measuring curves with ejection mode adhesion force tester under (a) ejection speed = 1.6 mm/sec, and (b) ejection speed = 59 mm/sec. (Resin = S70A, Ra = 0.08 μm).